QUANTITATIVE COMPARISON BETWEEN LOW ENERGY HIGH RESOLUTION (LEHR) AND MEDIUM ENERGY GENERAL PURPOSE (MEGP) COLLIMATOR ON NEMA SPECT IMAGING

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By

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Dissertation submitted in partial fulfilment
of the requirements for the degree of
Bachelor of Health Science (Honours) (Medical Radiation)

JUNE 2024

CERTIFICATE

This is to certify that the dissertation entitled “Quantitative Comparison between Low Energy High Resolution (LEHR) and Medium Energy General Purpose (MEGP) Collimator on Nema SPECT Imaging” is the bona fide record of research work done by Ms. Divya A/P Paramesivam during the period from October 2023 to July 2024 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Science (Honours) (Medical Radiation).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where previously stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

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DATE: …………………………

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LIST OF SYMBOLS

A	Activity of Radionuclide
A_0	Initial Activity of Radionuclide
cps	Counts per second
keV	Kiloelectronvolt
mm	Millimeter
mCi	Millicurie
Ci	Curie
MBq	Megabecquerel
$T_{1/2}$	Half- Life
cm	Centimetre

LIST OF ABBREVIATIONS

AVG	Average
FWHM	Full Width Half Maximum
HUSM	Hospital Universiti Sains Malaysia
TC-99M	Technetium- 99m
SNR	Signal- Noise- Ratio
USM	Universiti Sains Malaysia
SD	Standard Deviation
SPECT	Single Photon Emission Computed Tomography
MO-99	Molybdenum- 99
LEHR	Low Energy High Resolution
MEGP	Medium Energy General Purpose
PMT	Photomultiplier Tube
FOV	Field of View
MLEM	Maximum Likelihood Expectation Maximization
OSEM	Ordered Subset Expectation Maximization

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Appendix A LEHR CALCULATION OF SMALLER SPHERES

Appendix B MEGP CALCULATION OF SMALLER SPHERES

QUANTITATIVE COMPARISON OF IMAGE QUALITY BETWEEN LOW ENERGY HIGH RESOLUTION (LEHR) AND MEDIUM ENERGY GENERAL PURPOSE (MEGP) COLLIMATOR ON NEMA SPECT IMAGING

ABSTRAK

Perubatan nuklear menggunakan bahan radioaktif, yang dikenali sebagai radiofarmaseutikal atau radiopengesan, untuk mendiagnosis dan merawat penyakit. Bidang ini menggunakan biomarker radionuklid untuk memvisualisasikan fungsi fisiologi dan mengesan keabnormalan seperti sel kanser. Alat pengimejan seperti kamera gamma, yang merekodkan pancaran dari radiopengesan dalam badan, adalah penting dalam proses ini. Kamera gamma adalah mesin pengimejan penting dalam Perubatan Nuklear, membolehkan pengimejan dua dimensi proses tubuh menggunakan radiopengesan. Ia membantu dalam diagnosis penyakit, memantau fungsi jantung, dan mengesan tenaga radioaktif. Komponen kamera termasuk kolimator, kristal sintilasi NaI(Tl), pemandu cahaya, dan tiub fotoganda.

Kualiti sistem pengimejan perubatan nuklear dipengaruhi oleh faktor seperti ciri fizikal pengesan dan kolimator, algoritma rekonstruksi imej, pengecilan foton, penyerakan foton, dan pergerakan pesakit. Kolimator yang betul adalah penting untuk imej berkualiti tinggi, kerana ia menghadkan sudut penerimaan foton dan membenarkan maklumat tepat mengenai kedudukan awal pancaran foton. Tindakbalas kolimator terhadap sinar gamma ditentukan oleh diameter lubang, lebar septa, dan ketebalan septa. Pengimejan perubatan nuklear menggunakan empat jenis kolimator utama: lubang selari, lubang mencapah, lubang bertumpu, dan lubang pin. Jenis kolimator dipengaruhi oleh diameter lubang dan panjang septa.

Penyelidikan ini bertujuan untuk membandingkan kualiti imej yang diperoleh menggunakan kolimator Resolusi Tinggi Tenaga Rendah (LEHR) dan Tujuan Am Tenaga Sederhana (MEGP) dalam pengimejan perubatan nuklear. Kajian ini memberi tumpuan kepada menilai perbezaan dalam kepekaan, kontras, resolusi, dan nisbah isyarat-ke-hingar (SNR). Kajian fantom dilakukan menggunakan NEMA 2012/IEC 2008 dan sumber titik Tc-99m, menggunakan teknik pancaran Foton Tunggal Tomografi Berkomputer (SPECT). Kamera Gamma GE Discovery NM/CT 670 Pro digunakan, dan kedua-dua kolimator LEHR dan

MEGP diuji. Eksperimen ini melibatkan penyediaan Tc-99m, memperoleh imej, dan menganalisisnya untuk kepekaan imej, kontras imej, resolusi, dan SNR.

Analisis kepekaan imej, kontras imej, resolusi, dan SNR dalam kedua-dua kolimator LEHR dan MEGP menunjukkan variasi yang ketara. Kolimator MEGP menunjukkan kepekaan imej dan kontras imej yang lebih baik tetapi mengakibatkan resolusi yang lebih rendah dan hingar imej yang lebih tinggi. Sebaliknya, kolimator LEHR dengan lubang yang lebih kecil dan lebih dalam menghasilkan imej dengan resolusi yang tinggi dan hingar imej yang berkurang. Imej yang diperoleh dari kolimator MEGP menunjukkan nilai kepekaan imej purata sebanyak $4.716\,x\,10^4$ cps/Ci, manakala imej yang diperoleh dari kolimator LEHR menunjukkan kepekaan imej purata sebanyak $3.965\,x\,10^4$ cps/Ci. Imej yang diperoleh dari kolimator MEGP mempunyai nilai kontras imej purata sebanyak 0.982, manakala kontras imej purata dari kolimator LEHR adalah 0.976. Peleraian ruang purata yang diukur oleh FWHM untuk imej yang diperoleh dari kolimator LEHR adalah 5.64 mm, manakala nilai FWHM untuk imej yang diperoleh dari kolimator MEGP adalah 5.71 mm. Resolusi kolimator untuk yang kolimator LEHR adalah 3.69 mm, manakala resolusi kolimator untuk kolimator MEGP adalah 4.91 mm. Untuk SNR, nilai yang ditunjukkan oleh imej yang diperoleh dari kolimator LEHR adalah 83.997 manakala imej yang diperoleh dari kolimator MEGP menunjukkan nilai 77.064.

Penyelidikan ini menyoroti pertukaran antara kepekaan imej dan resolusi dalam pengimejan perubatan nuklear. Kolimator LEHR menawarkan resolusi yang lebih baik, manakala kolimator MEGP memberikan kepekaan imej yang lebih tinggi. Untuk mengoptimumkan kaedah pengimejan berdasarkan keperluan klinikal, perbandingan ini adalah penting dalam menentukan kualiti imej yang diperlukan.

QUANTITATIVE COMPARISON OF IMAGE QUALITY BETWEEN LOW ENERGY HIGH RESOLUTION (LEHR) AND MEDIUM ENERGY GENERAL PURPOSE (MEGP) COLLIMATOR ON NEMA SPECT IMAGING

ABSTRACT

Nuclear medicine leverages radioactive materials, known as radiopharmaceuticals or radiotracers, for diagnosing and treating diseases. This field uses radionuclide biomarkers to visualize physiological functions and detect abnormalities, such as cancer cells. Imaging tools such as gamma cameras, which record emissions from radiotracers inside the body, are essential to this process. The gamma camera is a crucial imaging device in Nuclear Medicine, enabling two-dimensional imaging of body processes using radiotracers. It aids in disease diagnosis, monitoring heart function, and detecting radioactive energy. The camera's components include a collimator, large-area NaI(Tl) scintillation crystal, light guide, and photomultiplier tubes.

Nuclear medicine imaging systems' quality is influenced by factors such as detector and collimator physical characteristics, image reconstruction algorithms, photon attenuation, scattering, and patient motion. The right collimator is crucial for high-quality images, as it limits photon acceptance angle and allows precise information about the photons' initial emission position. The collimator response to gamma rays is determined by hole diameter, septa width, and septa thickness. Nuclear medicine imaging uses four primary collimator types: parallel-hole, diverging-hole, converging-hole, and pinhole. The type of collimator is influenced by hole diameter and septa length.

This research aims to compare the image quality obtained using Low Energy High Resolution (LEHR) and Medium Energy General Purpose (MEGP) collimators in nuclear medicine imaging. The study focuses on assessing differences in sensitivity, contrast, resolution, and signal-to-noise ratio (SNR). A phantom study was conducted using a NEMA 2012/IEC 2008 phantom and Tc-99m point source, by using SPECT technique. The GE Discovery NM/CT 670 Pro Gamma Camera was employed, and both LEHR and MEGP collimators were tested. The experiment involved preparing Tc-99m, acquiring images, and analyzing them for image sensitivity, image contrast, resolution, and SNR. The study measured and compared the performance of LEHR and MEGP collimators.

The analysis of image sensitivity, image contrast, resolution, and SNR in both LEHR and MEGP collimator revealed significant variations. MEGP collimator showed better image sensitivity and image contrast but also resulted in degraded resolution and higher image noise. Conversely, the LEHR collimator with their smaller and deeper holes, resulted image with profound resolution and reduced image noise. Image acquired from MEGP collimator exhibited average image sensitivity value of $4.716\ x\ 10^4$ cps/Ci, while image acquired from LEHR collimator exhibited an average image sensitivity of $3.965\ x\ 10^4$ cps/Ci. Image acquired from MEGP collimator had an average image contrast value of 0.982, while the average image contrast of image acquired from LEHR collimator is 0.976. The average spatial resolution measured by FWHM for image acquired from LEHR collimator is 5.64 mm, while the FWHM value of image acquired from MEGP collimator is 5.71 mm. The collimator resolution of LEHR collimator is 3.69 mm, while the collimator resolution of MEGP collimator is 4.91 mm. For SNR, the value exhibited by image acquired from LEHR collimator is 83.997 while image acquired from MEGP collimator exhibited a value of 77.064.

The research highlights the trade-offs between image sensitivity and resolution in nuclear medicine imaging. LEHR collimator offers superior resolution, while MEGP collimator provide higher image sensitivity. In order to optimize imaging methods based on clinical requirements, this comparison is essential in determining the quality of image required.

Keywords: Nuclear medicine, Gamma Camera, LEHR, MEGP, Image Quality, Sensitivity, Resolution, Tc-99m.

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Nuclear medicine is a branch of medical imaging that utilizes small amounts of radioactive materials, known as radiopharmaceuticals or radiotracers, to diagnose and treat diseases. It offers special insights into the composition and operation of the body's tissues and organs. Nuclear medicine imaging utilizing radionuclides operates on the principle of using radioactive substances, known as radionuclide biomarkers, to visualize physiological organ functions and detect abnormalities like cancer cells at a molecular level. (Ramamoorthy, 2018) The selection of radionuclides is based on certain characteristics, like half-life and decay emissions. With the use of specialized imaging equipment, these emissions can be identified externally. To make a radiotracer, the chosen radionuclide is typically mixed with a chemical that is physiologically active. The patient is subsequently given this radiotracer, usually via injection, ingestion, or inhalation. The radiotracer is intended to target particular bodily chemicals or physiological processes. For instance, radiotracers may be engineered to accumulate in tumor cells as a result of their greater metabolic activity or the expression of certain receptors in cancer imaging. The radionuclide releases positrons or gamma rays as it decays radioactively inside the body. These emissions are detected by external detectors like positron emission tomography (PET) scanners and gamma cameras.

The gamma camera is a major imaging device used in Nuclear Medicine to enable two-dimensional imaging of physical processes occurring within the body with the aid of radiotracers inserted into patient's body. Gamma cameras are known to be a vital imaging tool that physicians can employ to picture many physiological processes, monitor heart function, and aid in disease diagnosis. Moreover, it detects radioactive energy released from the patient's body and transforms it into an image using specialized imaging techniques such as planar dynamic or single-photon emission-computed tomography (SPECT). The major components in a gamma camera are, a collimator, a large-area NaI(Tl) scintillation crystal, a light guide, and an array of photomultiplier tubes (PMT). Figure 1 shows the gamma camera unit used in HUSM and Figure 2 illustrates the basic principles and components of the gamma camera.

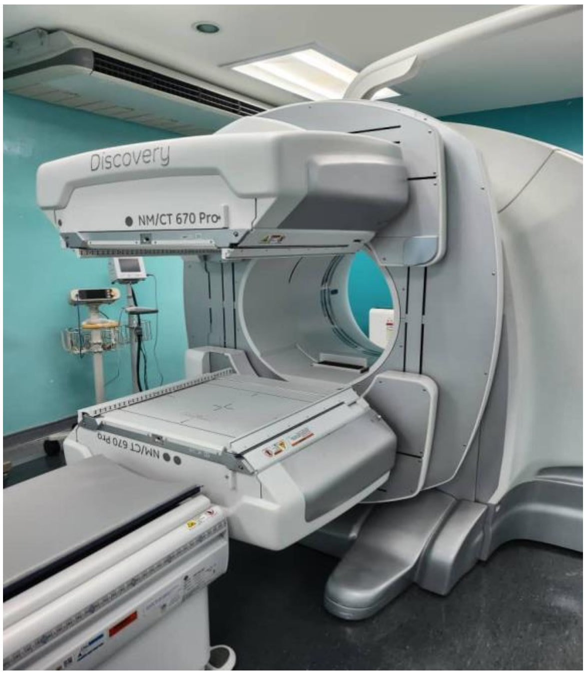

Figure 1: GE Discovery NM/CT 670 Pro Gamma Camera at HUSM

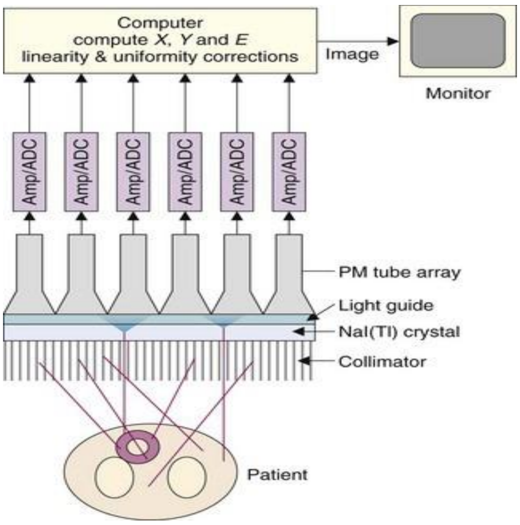

Figure 2: Basic Principles and Components of the Gamma Camera.

Cited from: Themes, U., 2016

As the radiotracer decays, it releases gamma rays, which move in the direction of the detector. In order to ensure that the gamma rays travel at a precise angle with respect to the detector crystal, they must pass through collimators. The gamma rays are transformed into light by the NaI(Tl) scintillation crystal. Hence, the light is converted into electrical impulses by the PMT. Ultimately, The outputs of each PMT are amplified and digitized using an analogue-to-digital converter (ADC). The X-Y locations for each gamma ray that interacts in the NaI(Tl) crystal are computed from the digitized signals.

There are numerous factors, including the physical characteristics of the detector and collimator, image reconstruction algorithms, photon attenuation and scattering, and patient motion, can impact the quality of images obtained from nuclear medicine imaging systems. The use of the right collimator while imaging with a particular radioisotope is crucial to obtain a high-quality image. By limiting the incident photon acceptance angle, the collimator, which is typically a thick lead sheet with many fine holes, allows precise information about the photons' initial emission position to be obtained. (Noori-Asl & Jeddi-Dashghapou, 2022) The collimator response to the gamma rays released in various directions is determined by the combination of three parameters: hole diameter, septa width, and collimator thickness. Moreover, the geometric field of view is determined by the collimator in use, which also has a major impact on the detector’s sensitivity and spatial resolution. Nuclear medicine imaging uses four primary collimator types, parallel-hole, diverging-hole, converging-hole, and pin-hole collimators. Depending on the area being scanned, any one of these collimators may be employed. However, parallel-hole collimators are most commonly used in clinical imaging. (Pandey et al., 2015)

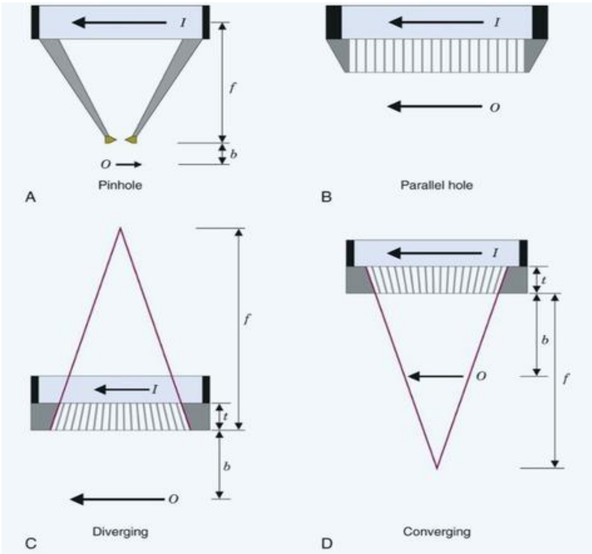

Figure 3: Types and shapes of collimators.
Cited from: Gomes, M. I. (2014)

Parallel-hole collimators can be classified as high-resolution, all purpose and high sensitivity types or low-energy, medium-energy and high-energy types based on the resolution and sensitivity they accommodate in imaging. The types of parallel-hole collimators can be differentiated by the collimator hole diameter and the length of septa. Thin septal with large collimator hole diameter results in image with high sensitivity but low resolution, and vice-versa. However, thickness of septa must be increased as the energy of photon increase to prevent cross-talk. Besides that, the length of septa also effects the image being produced. A lengthy septa reduces the detection probability which results in high resolution image but with low sensitivity. Hence, a short septa increases the detection probability of the gamma rays which results in high sensitivity but low resolution image due to the non-parallel gamma rays also being detected. (Azarm et al., 2015) Figure 3 illustrates differences between several types of parallel-hole collimators.

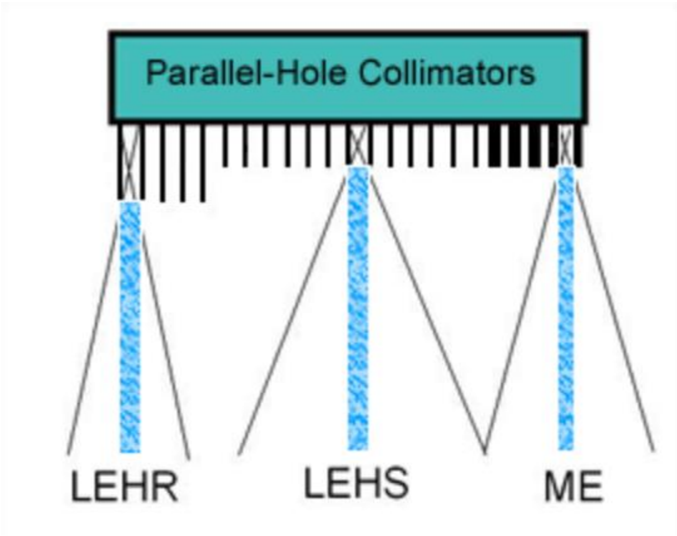

Figure 4: Types of parallel-hole collimators.
Cited from: Crosthwait, M. H.

1.2 Aim

This research is going to assess the difference in quality of SPECT image acquired between both LEHR and MEGP collimators by comparing the sensitivity, contrast, resolution and signal noise ratio (SNR).

1.3 Objectives

This study is aimed to compare the difference in the quality of image acquired between LEHR and MEGP collimators using NEMA Phantom filled with Tc-99m source in a SPECT imaging.

The specific objectives of this study are:

i. To prepare the specific activity of Tc-99m in NEMA phantom for the image acquisition.
ii. To calculate the sensitivity, contrast, resolution, and signal noise ratio (SNR) on the SPECT NEMA phantom image produced using LEHR and MEGP collimator.
iii. To analyze the image quality acquired between LEHR and MEGP collimator.

1.4 Problem Statement and Significance of Study

In an ideal parallel-hole collimator, only those photons that travel parallel to the collimator holes can pass through the holes and reach the detector surface. Consequently, to exclude all photons traveling in different directions, the perfect collimator should have a thickness that is large enough and the septal length has to be long enough. However, in order to boost the imaging system's sensitivity, thinner collimators with bigger hole sizes are needed, which results in a decrease in the imaging system's spatial resolution because of the increased photon acceptance angle. At this point, the septa has to compensate in its length to enable the photon reaching the detector. In order to prevent significant reductions in sensitivity and spatial resolution, the ideal collimator thickness and length must be selected within these two parameters.

However, a major issue in SPECT imaging is balancing the trade-off between sensitivity and resolution (Van Audenhaege et al., 2015). Increased sensitivity in SPECT imaging makes it possible to detect faint signals where even the small angle scattering is counted and resembled in images. Besides that, increased resolution improves image clarity and makes it possible to identify finer details. Compromising even either one of this characteristic may affect the detection efficiency in diagnostic imaging (Zhang & Zeng, 2007). However, in previous studies the difference in the quality of image obtained from different collimator structure is still not well documented and differentiated based on their clinical purposes. Hence, this research is going to compare the quality of image acquired from, LEHR and MEGP collimator, by analysing the sensitivity, contrast, resolution and signal noise ratio (SNR).

CHAPTER 2
LITERATURE REVIEW

2.1 Principle of Gamma Camera

A key technique in nuclear medicine is gamma camera imaging. It can be utilized for a wide range of medical research, including tumour detection, bone development measurement, heart muscle blood flow evaluation, and diagnostic imaging of metabolically active regions and organ function. This practical application combines ideas from geometric optics, nuclear physics, data processing, picture generation, calibration, and medicine (Lowe et al., 2022). The SPECT system invented to obey the gamma camera, involves mounting a scintillation camera around the patient's body and connecting it to an appropriate computer system. In a SPECT imaging, A series of planar images are taken while the camera rotates 180 ´ or 360 ˚ around the patient. This is the fundamental idea of a SPECT system that depends on the rotating camera concept. It is employed in clinical research to improve imaging quality and facilitate diagnosis (Hasan et al., 2017).

The gamma camera is composed of numerous components, each of which has a distinct purpose in translating gamma rays into light images so that humans may view the proper image. The collimator, sodium iodide (NaI) crystal, photomultiplier tubes (PMT), and position logic circuit are the fundamental parts of a gamma camera. The basic principle and components of gamma camera can be seen in Figure 2. The detected gamma rays are essential for image formation. Firstly, the direction of the discovered γ rays is defined using an image collimator. The most popular type of collimator is current clinical practice parallel hole collimator. The collimator creates a projected image of the γ-ray distribution on the surface of the NaI(Tl) crystal by regulating which γ rays are received (Cherry et al., 2004).

In-vivo detection of gamma rays involves using imaging technologies to visualize the distribution of radionuclides within a living organism. When radionuclides are injected into the body, gamma photons are released, which are detected by the gamma camera. Usually, these radionuclides are attached to physiologically active compounds that aim to target particular tissues, organs, or cell receptors. Hence, there are significant challengers that follows based on collimation, scattering and attenuation during radiation detection of the radionuclide.

According to the study by Cherry, Sorenson, & Phelps, in order to improve image resolution in gamma ray imaging, collimation is necessary to guarantee that the detected photons originate from certain directions. Collimators are devices that stop photons from following pre-set pathways. They are constructed of materials with large atomic numbers, such as lead (Cherry, Sorenson, & Phelps, 2012). Besides that, according to study by Zaidi & Montandon, there are various ways that gamma rays interact with materials, but Compton scattering is especially challenging for in-vivo detection. When gamma rays and electrons meet, a change in the direction and energy of the gamma rays results in Compton scattering. When scattered photons reach the detector, they can cause artifacts and muddy the boundaries of the image. These photons are frequently identified as coming from inaccurate locations, which causes errors in the imaging of the radionuclide distribution. The study also included the techniques such as energy discrimination and scatter correction algorithms are employed to mitigate the effects of scattering (Zaidi & Montandon, 2007).

Additionally, the study by Vija, stated that attenuation refers to the decreased gamma rays' intensity as they travel through the body. The non-uniform attenuation results from the varied degrees to which different bodily tissues attenuate gamma radiation. In contrast to soft tissue, bone absorbs more gamma rays, which results in differences in observed signal intensity that do not correlate with radionuclide concentrations. The study also addressed the attenuation correction method. These include the use of computational models that estimate and adjust for attenuation based on the known properties of tissues, or transmission scans, which map the attenuation properties of the body using a known source of gamma rays (Vija et al., 2009).

2.2 OSEM Image Reconstruction Algorithm

For image reconstruction in Single Photon Emission Computed Tomography (SPECT) imaging, the Ordered Subset Expectation Maximization (OSEM) technique is frequently utilized. Compared to more conventional techniques like filtered back projection (FBP), this iterative method increases both the speed and quality of picture reconstruction. As an expansion of the Maximum Likelihood Expectation Maximization (MLEM) technique, OSEM was created with the enormous datasets commonly seen in medical imaging in mind. The division of the dataset into smaller subsets, which are analysed one after the other during each iteration, is the fundamental characteristic of OSEM. As a result, computational complexity is decreased and convergence is accelerated.

A study by De Barros, stated that it would not be suitable to use the MLEM algorithm in a clinical setting due to its delayed convergence process. As a result, in 1994, Hudson and Larkin introduced the ordered-subset expectation maximization (OSEM) algorithm, a variant of the MLEM technique, with the aim of utilizing it to speed up the process of reconstructing images. The study also stated that, by splitting the entire collection of projections into smaller subsets, the fundamental idea of OSEM is achieved. The number of projections is the same for each subgroup. Furthermore, a multiple of the total number of projections can be achieved in terms of the subgroup creation count (De Barros et al., 2015).

Besides that, a study by Aijing stated that In OSEM, an image will only need to be updated once after one group of pixels in the reconstructed picture have been corrected. The reconstructed picture can be updated n times if all n subsets are employed in a single iterative procedure. Due to that, OSEM converges more quickly than the conventional MLEM method, whose reconstruction picture updates just once every iteration. This study also emphasized the advantages of using the OSEM image reconstruction algorithm. For instance, OSEM iteratively improves the image estimate, hence it yields pictures with less noise than FBP. Additionally, Improved image quality is possible because of OSEM's iterative design, which makes it possible to simulate the physical and statistical characteristics of the imaging system with greater accuracy (Aijing et al., 2018).

2.3 Collimators

Collimators are crucial components in gamma ray imaging systems. They contribute to the improvement of image resolution and contrast by ensuring that only gamma rays moving in particular directions reach the detector. The choice and layout of a collimator not only greatly affect imaging performance but also bring up a number of collimation and external radiation-related issues. A study by Zaidi & Hasegawa, stated that the use of collimators is crucial in nuclear imaging to reduce the detection of scattered radiation, thereby enhances the image quality and. The study highlighted that the collimators block incoming gamma rays' trajectories so that only those going in certain directions can reach the detector. Due to its ability to reduce the detection of scattered and off-angle photons, which have the potential to blur the image, this directional control is essential for preserving good image quality (Zaidi & Hasegawa, 2003).

The beam collimators used in conventional radiography are not the same as the collimators of gamma cameras, which are employed in nuclear medicine. Usually, they are made of a lead disc that has thousands of closely spaced holes bored into it, each spaced apart by septa.

Collimators merely only allows photons travelling along designated paths to pass through, while providing information regarding the direction of the photons that strike the detector. The septa absorbs any other rays that are directed in different directions, thus they don't add anything to the image. Therefore, precise spatial localization is the main purpose of the collimator in gamma cameras. The collimator is placed over the scintillator crystal of the Gamma camera, and positioned as close as possible to the patient, to maximise spatial resolution (Murphy & Vajuhudeen, 2020). There are various types of collimators, including LEHR and MEGP, where each is designed for different imaging purposes and energy levels.

A lot of studies were done on comparing the quality of image produced from MEGP collimator and LEHR collimator, where the results had major drawbacks of balancing the trade-off between sensitivity and spatial resolution. Septal penetration of high-energy photons causes LEHR collimators to have better spatial resolution which improves image clarity, but lower contrast. However, MEGP collimators offer lower background noise and better count sensitivity, which enhances lesion detectability **(**Gregory et al., 2016). This research is going through the path of assessing the different magnitude in image quality between bot collimators by comparing the detector sensitivity, image contrast, spatial resolution and signal-noise-ratio.

2.3.1 LEHR Collimator

LEHR collimator is a specialized device used in conjunction with gamma cameras to enhance the imaging of low-energy gamma-emitting radionuclides, such as Technetium-99m (Tc-99m). For detailed diagnostic imaging, an LEHR collimator is especially helpful since its main function is to increase picture resolution while retaining sufficient sensitivity (Amuasi & Boadu, 2013). LEHR collimators are typically constructed from dense materials such as lead or tungsten, which effectively block gamma rays. The collimator consists of a grid of parallel holes, usually with hexagonal or circular cross-sections, that are precisely aligned to allow only gamma rays traveling directly from the patient to the detector, thereby reducing scatter and improving image clarity.

Permitting only gamma rays that are almost perpendicular to the detector to pass through, the LEHR collimator's design improves spatial resolution in comparison to general-purpose collimators due to its longer bore length and smaller hole size. The performance of a LEHR collimator is determined by the diameter and length of the holes. As a result, there are fewer dispersed or off-angle photons that might cause image blurring. However, because of the collimator holes' limiting nature, fewer gamma rays are detected overall, which results in a decrease in sensitivity despite the higher resolution (Cherry et al., 2004).

In clinical settings where precise diagnosis requires high-resolution images, LEHR collimators are especially helpful. They are frequently employed in procedures where precise viewing of minute structures is crucial, such as thyroid imaging, cardiac perfusion imaging, and bone scintigraphy. Therefore, LEHR collimators are an essential component in nuclear medicine imaging, providing the high-resolution images needed for precise diagnostic evaluations. By understanding their design and application, healthcare providers can effectively utilize these collimators to improve patient outcomes through better imaging techniques (Bolus, 2008).

2.3.2 MEGP Collimator

In nuclear medicine imaging, MEGP collimator is used to balance sensitivity and resolution for medium-energy gamma-emitting radionuclides. These collimators can be utilized for a different range of diagnostic applications because they are made to accommodate higher intensity gamma rays than those used with LEHR collimators. MEGP collimators are constructed from dense materials like lead or tungsten, similar to other types of collimators. A grid of holes, which may be round or hexagonal, is part of the design. Compared to low-energy collimators, MEGP collimators have larger holes and thicker septa. This structure aids in controlling the higher energy gamma rays released by radionuclides like Iodine-131and Indium-111 (Cherry et al., 2004). The septa in MEGP collimators are designed to be thicker to prevent high-energy gamma photons from penetrating and causing image artifacts, that will affect the quality of images being produced.

The goal of the MEGP collimator is to give medium-energy gamma rays a compromise between sensitivity and resolution. The thicker septa and bigger hole sizes aid in preventing higher-energy photons from passing through the septa, which would cause noise and scatter, which would reduce image quality. However, in comparison to LEHR collimators, this yields a middling resolution. Studies have shown that images obtained using MEGP collimators exhibit better body-to-background appearance, more clearly defined areas of increased uptake, and overall better contrast and appearance for reading and technical quality control purposes (Edwards & Zhuang, 2014).

In clinical situations where medium-energy radionuclides are used, MEGP collimators are utilized. Higher energy gamma photons can provide more accurate diagnostic information, hence these radionuclides are frequently utilized to image cancers, infections, and other diseases. Specific applications include imaging with In-111 labelled leukocytes to detect infections and using I-131 for thyroid cancer imaging and therapy (Bolus, 2008). The compromise in resolution means that MEGP collimators may not provide as high-resolution images as LEHR collimators for low-energy photons. This trade-off must be considered when selecting the appropriate collimator for a specific diagnostic task.

2.4 SPECT Image Quality

Acquiring the finest quality images from this imaging system is crucial for diagnosis purposes, as SPECT is one of the most frequently utilized imaging technologies in clinical nuclear medicine. In view of this, it is crucial to look into the various elements that affect the quality of SPECT images. A study done by Noori-Asl, had examined how various factors, including the arc of rotation, the number of angular views, the size of the image matrix, the pixel size in projection images, the impact of various collimators, the impact of using a filter during image reconstruction, and the impact of using the scatter correction method on 99mTc SPECT images, affect the quality of SPECT images (Noori-Asl, 2020).

Image quality in SPECT imaging is influenced by several factors including spatial resolution, contrast, noise, and artifacts. The intrinsic resolution of the gamma camera, the collimator design, and the separation between the detector and the source are some of the factors that restrict the spatial resolution in SPECT. Contrast is the difference in counts or intensity between different regions within the image. Noise in SPECT images arises from statistical fluctuations in the detected counts due to the inherent randomness of radioactive decay and photon detection. Scattered photons can reach the detector from incorrect angles. The scattered events contributes to noise, thus the collimator aids to confine the detection in terms of accurate distribution and detection events. Such errors or distortions in the image that do not accurately depict genuine functional or anatomical features are called artifacts. SPECT artifacts commonly result from patient mobility, inadequate compensation for photon attenuation, and detecting system malfunctions (Hutton & Nuyts, 2007).

2.4.1 Detector Sensitivity and Resolution

The trade-off between resolution and sensitivity in SPECT imaging is a key challenge. increased sensitivity in SPECT makes it possible to detect faint signals, while increased resolution improves image clarity and makes it possible to identify finer details. However sensitivity frequently declines as resolution rises, and vice versa. There is a trade-off present in different SPECT imaging methods.

Sensitivity refers to the system's ability to detect gamma photons emitted from the radiotracer within the patient. More photons are recognized with higher sensitivity, which enhances count statistics and lowers image noise. In addition to improving patient comfort and lowering motion artifacts, this results in sharper images and faster acquisition times. But in order to achieve high sensitivity, collimators with bigger holes or shorter bore lengths are usually used; these features let in more photons to the detector but also increase the possibility of scattered photons entering the system, which lowers spatial resolution and contrast in images (Cherry, Sorenson, & Phelps, 2012).

In contrast, resolution describes the system's capacity to discriminate between two nearby spots or structures inside the imaging field. To precisely localize and characterize lesions or abnormalities, high resolution is necessary for accurately showing small or closely spaced components. Collimators with longer bore lengths or smaller holes are frequently needed to achieve high resolution because they limit the angle at which photons may reach the detector. This lowers the number of detected photons and, in turn, the sensitivity of the system (Hutton & Nuyts, 2007).

The trade-off between sensitivity and resolution is largely dependent on the type and design of the collimator. Although they sacrifice spatial resolution, collimators with large holes (also known as low-resolution collimators) increase sensitivity by letting more photons reach the detector. On the other hand, because fewer photons may flow through narrow-hole collimators, or high-resolution collimators, they increase spatial resolution but decrease sensitivity (Patton, Turkington, & Coleman, 2002).

Most study investigated the use of advanced image reconstruction algorithms to enhance both sensitivity and resolution. For example, the study by Hutton & Nuyts, employed iterative reconstruction, which improves sensitivity and resolution by accounting for scatter and attenuation and more precisely modelling the mechanics of photon detection. These algorithms can improve image quality without noticeably lowering sensitivity or resolution, which helps to partially offset the trade-off (Hutton & Nuyts, 2007). The clinical application determines the ideal ratio of sensitivity to resolution in SPECT imaging. For example, neurological imaging may prioritize higher resolution to detect minute lesions or abnormalities in the brain, whereas cardiac imaging may emphasize higher sensitivity to capture dynamic events across time.

2.4.2 Image Contrast and Signal Noise Ratio

In SPECT imaging, there is an inherent trade-off between contrast and signal-to-noise ratio (SNR). It is essential to comprehend and maintain this equilibrium in order to maximize image quality and guarantee precise diagnostic data. The term "contrast" describes the variation in signal strength between various areas of an image, which makes it possible to identify anomalies and structures. In order to distinguish regions with different amounts of radiotracer uptake, which is crucial when diagnosing lesions or functional abnormalities, high contrast is required. The signal strength in relation to the background noise is measured by SNR. Since noise can obfuscate details and lower the image's overall quality and dependability, high SNR is essential for creating images that are readable and clear.

According to the study by Cherry, Sorenson, & Phelps, higher counts, or more detected photons, increase SNR by lowering the statistical noise present in the imaging process. However doing so frequently calls for greater radiotracer dosages or longer acquisition periods, which can compromise the comfort and safety of the patient. Besides that, the usage of collimators with larger holes increases photon detection efficiency (higher sensitivity), improving SNR. However, by letting more scattered photons enter the detector, this may lessen contrast and cause the image to become blurry (Cherry, Sorenson, & Phelps, 2012).

According to study by Hutton & Nuyts, Extending acquisition time improves SNR by allowing more photon counts to be collected. Longer durations, however, may cause the patient to move, which reduces contrast by introducing motion artifacts and blurring the image. Through limiting the angle of incoming photons, collimators with smaller holes increase contrast and spatial resolution, but they also decrease sensitivity and SNR because fewer photons are detected. This study also implied filter application during image reconstruction. Filters can be applied during image reconstruction to improve contrast by reducing noise, but if they are applied too aggressively, they may smooth out crucial details, lower signal-to-noise ratio, and possibly mask microscopic lesions (Hutton & Nuyts, 2007).

The ideal ratio of contrast to SNR in SPECT imaging relies on the particular diagnostic needs and the clinical setting. For instance, in cardiac imaging, keeping a high signal-to-noise ratio (SNR) may be given priority in order to precisely quantify myocardial perfusion, but in oncological imaging, strong contrast is necessary to differentiate malignancies from surrounding tissues.

2.4.3 Image Quality using LEHR and MEGP Collimator

Collimators are essential for determining image quality in SPECT imaging. The Medium-Energy General-Purpose (MEGP) collimator and the Low-Energy High-Resolution (LEHR) collimator are two frequently used collimator types. Different types have different properties that affect image quality, especially in terms of sensitivity, spatial resolution, and artifact reduction. The LEHR collimator is designed to provide high spatial resolution for imaging low-energy gamma photons, typically in the range of 100-200 keV. It is often used for imaging isotopes like technetium-99m (Tc-99m).

According to the study by Cherry, Sorenson, & Phelps, LEHR collimators have small hole sizes and thin septa, which allow for precise localization of gamma photon emissions, leading to high spatial resolution. This is very useful for identifying tiny lesions and imaging tiny anatomical features. The tiny septa reduce artifacts and enhance image quality by limiting gamma ray penetration via the collimator material (Cherry, Sorenson, & Phelps, 2012). Besides that, according to the study by Zaidi & Hasegawa, LEHR collimators are more prone to scatter artifacts because they are optimized for low-energy photons, which are more likely to be scattered within the body and degrade image quality. The small hole sizes are capable to reduce the number of gamma photons that reach the detector, which can lower sensitivity of image as well (Zaidi & Hasegawa, 2003).

The MEGP collimator is designed for imaging medium-energy gamma photons, typically in the range of 200-400 keV. It is used for isotopes such as iodine-131 (I-131) and gallium-67 (Ga-67). According to the study by Patton, Turkington, & Coleman, compared to LEHR collimators, MEGP collimators have bigger hole diameters and thicker septa, which improves photon detection efficiency, particularly for medium-energy gamma emissions. This shortens acquisition times and increases sensitivity. Higher-energy photons are effectively blocked by the thicker septa, which lowers septal penetration artifacts and enhances image quality (Patton, Turkington, & Coleman, 2002).

However, there are study that highlights the drawbacks due to the usage of MEGP collimator in SPECT imaging. For example, the study by Cherry, Sorenson, & Phelps, stated that compared to LEHR collimators, the larger hole sizes needed to retain sensitivity leads to a lower spatial resolution. This may make it harder to distinguish small structures and objects that are close together. MEGP collimators are heavier and more complicated due to their thicker septa and greater dimensions, which can make handling and placing them during imaging processes more difficult (Cherry, Sorenson, & Phelps, 2012).

Most study stated that the choice between LEHR and MEGP collimators depends on the clinical application and the specific isotopes used in the imaging study. LEHR collimator is optimized for high spatial resolution at the expense of sensitivity, ideal for detailed imaging of small structures with low-energy isotopes. MEGP collimator offers a lower spatial resolution than LEHR but a superior photon detection efficiency for medium-energy isotopes when sensitivity and resolution are balanced.

Table 1: Collimators Suited to Different Radionuclides & Clinical Applications

Collimator Type	Radionuclides	Photon Energy Range (keV)	Clinical Purposes
LEHR	Technetium-99m	140	○ Myocardial Perfusion Imaging ○ Bone Scan ○ Renal Scan
	Iodine-123	159	○ Brain Imaging ○ Thyroid Imaging
	Xenon-133	81	○ Pulmonary Ventilation Studies
	Thallium-201	135, 167	○ Myocardial Perfusion Imaging
MEGP	Indium-111	171, 245	○ Infection Imaging ○ Neuroendocrine Tumours
	Iodine-131	364	○ Whole Body Scan
	Gallium-67	93, 184, 300, 393	○ Tumour Imaging ○ Lymphoma Imaging

CHAPTER 3
MATERIALS AND METHODS

3.1 Materials

In this chapter, the specification and descriptions of the materials involved in this research were discussed. Meanwhile, the method of conducting the experiment will also being discussed in this chapter. Specifically, from the phantom medium preparation to data acquisition.

3.1.1 Gamma Camera

The GE Discovery NM/CT 670 Pro Gamma Camera was used in this study where it consists of two detector heads (Detector 1 and Detector 2) as shown in Figure 5. This machine can improve dose management while cutting down on acquisition time, making patient scheduling more convenient. Its layout is intended to assist with obtaining SPECT and CT scans easier. A cantilevered patient table, an acquisition workstation, and a Xeleris review and processing workstation are also included in the machinery. Thereotically, when a patient receives radiopharmaceuticals, they ordinarily emit radiation, which the gamma camera unit's detector will pick up on. In order to create an image, the detected radiation arrays will first be transformed into light pulses and subsequently into electric signals (Mettler & Guiberteau,2006). Apart from detector, a gamma camera unit is also be mounted with a collimator. Before the radiation arrays are picked up by the detector, they must be redirected from the radionuclide source via a collimator. In this study, dual detector was activated to perform a SPECT imaging of NEMA phantom, with two collimators were used, which are LEHR collimator and MEGP collimator.

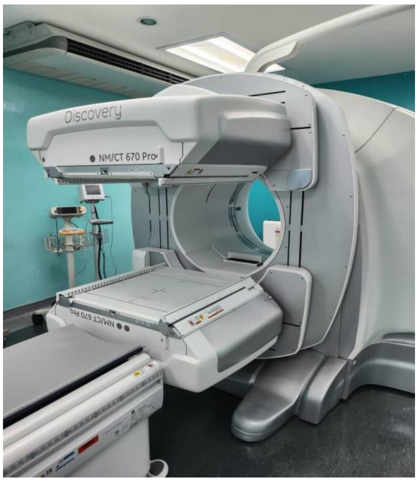

Figure 5: GE Discovery NM/CT 670 Pro Gamma Camera

3.1.1.1 LEHR Collimator

Low Energy High Resolution collimator is a type of parallel hole collimator that was used for this phantom study to evaluate the quality of image being produced. Compared to LEAP, LEHR collimators produce images with higher resolution. They have a greater number of deeper and smaller collimator holes. For a 1μCi source, the sensitivity is roughly 185,000 cpm, and the resolution is higher, measuring 0.65 cm at 10 cm from the patient side of the collimator (Buvat et al., 2001). LEHR collimator has its own specification as stated in Table 2. Figure 6 illustrates the LEHR collimator mounted on the gamma camera before the experiment was to be carried out. Figure 7 illustrates the septal feature of the LEHR collimator.

Table 2: Specifications of LEHR Collimator

Specifications	LEHR Collimator
Hole Shape	Hexagonal
Collimator Hole Diameter (mm)	1.4
Hole Length (mm)	32.8
Hole Diameter (mm)	1.9
Septal Thickness (mm)	0.152
Sensitivity (cpm/ μCi)	240
Collimator Resolution at 10cm (mm)	6.3
Planar Resolution (mm)	7.4

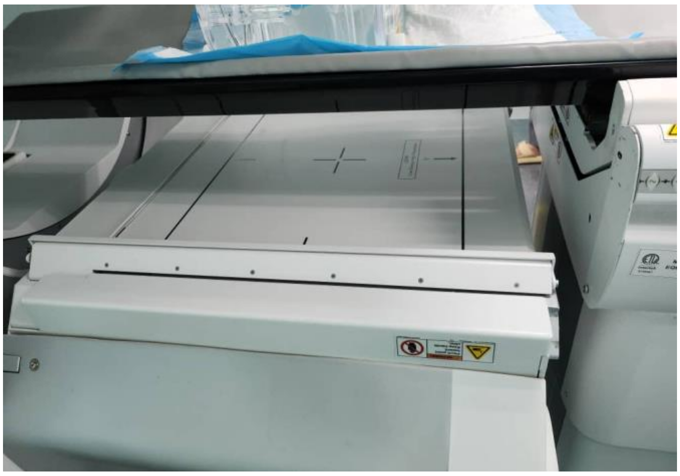

Figure 6: LEHR Collimator mounted on the Gamma Camera

Figure 7: LEHR Collimator Septal Illustration

3.1.1.2 MEGP Collimator

Medium Energy General Purpose collimator is a type of parallel hole collimator that was used for this phantom study to evaluate the quality of image being produced. For medium energy photons of nuclides like Krypton81, Gallium67, and Indium111, Medium Energy Collimators are employed. Compared to a low-energy collimator, these feature thicker septa, which is required to reduce septal penetration when imaging more energetic radiopharmaceuticals. (Wooten & Tran, 2010) MEGP collimator has its own specification as stated in Table 3. Figure 8 illustrates the MEGP collimator mounted on the gamma camera before the experiment to be carried out. Figure 9 illustrates the septal feature of the MEGP collimator.

Table 3: Specifications of MEGP Collimator

Specifications	**MEGP Collimator**
Hole Shape	Hexagonal
Collimator Hole Diameter (mm)	2.95
Hole Length (mm)	48.0
Hole Diameter (mm)	3.0
Septal Thickness (mm)	1.143
Sensitivity (cpm/ μCi)	1000
Collimator Resolution at 10cm (mm)	10.7
Planar Resolution (mm)	11.3